Collegiate Wind Competition Project Development

Final Report

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EXECUTIVE SUMMARY

This capstone team is an embodiment of NAU's participation in the Colligate Wind Competition (CWC). Part of the competition includes a project development contest where the goal is to develop a theoretical 100MW or less wind farm in the western half of South Dakota. With the development, the team must include a preliminary design, financial model, risk assessment, and detailed design. The team will use information obtained through research and faculty to adapt solutions to the primary objectives. The competition will prepare the team with real-world industry experience to be able to enter the wind industry sector.

The competition, project development contest, will be composed of a single final deliverable and presentation on the projected wind farm. This deliverable will include a site within the defined project location set by the competition, a preliminary wind farm design, a cost of energy and cash flow analysis for the 20-year expected project life, a risk management plan, and a finalized detailed design of the site plan. The site must not be on any existing wind farm or on one that is underdeveloped, and the team must be prepared to provide reasoning as to why the location was selected. For the preliminary wind farm design, the team must draft a preliminary design that includes turbine characteristics and the project boundary. In this section, the team must also research the site characteristics: terrain, vegetation, wind resource, wildlife, and land ownership. Also, the team must collect information for permitting to follow local ordinances, as well as protect sensitive species, sensitive wildlife, and mitigation processes. The financial aspect of the project includes initial capital cost, annual operating expenses, net annual energy production, market conditions, financing plan, and incentives to ensure the developed project is economically viable. The fourth requirement is to develop a risk management plan. This requires the team to research unknowns, uncertainties, and delays that can occur in a wind farm development. All of the risks must include a probability of occurrence and consequence if each risk occurred. The project should balance the financial and technical elements to be successful. The last step is to finalize the detailed design of the site plan. These steps must include collecting site data (ex. wind resource, contour, roughness data, etc.), turbine locations and array, site access roads, transmission to closest substation, and land leases. To be successful in competition, the team must accomplish all these objectives.

The team has developed a wind farm in Perkins County, South Dakota. Seventeen turbines will be used to generate 370008.9 MWh with a capacity factor of 29.7%. The site location is owned by one landowner that will be incentivized, so the development can occur. This makes this location ideal. Another positive aspect is that major species do not migrate through the site. Also, the site does not affect any Native American land. The chosen turbine is the Siemens Gamesa SG 5.8MW – 155. This turbine has a hub height of 102.5 meters with a rotor diameter of 155 meters. The team will follow local permitting regulations, as well as state and federal. The financial plan will be a Power Purchase Agreement (PPA) Partnership Flip with debt with a PPA price of 7.20 cents/kWh. These results are a levelized cost of energy (LCOE) of 5.71 cents/kWh with a flip year of 18. The net present value is greater than one for both the investor and developer which means the project is viable. The debt to equity ratio is greater than one (1.38), therefore, the team will be using local construction companies to build and decommission the project. At the end of the project, parts will be recycled or donated to local schools. The team has research risks that could occur. The local construction companies will be hired to help mitigate these risks over the project life, as well as assist in road construction. The team has research and developed all areas needed for the competition.

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1 BACKGROUND

1.1 Introduction

The goal of the project is to complete a project development of a 100 MW or less wind farm in western South Dakota. To complete this project, the team drafted a preliminary design, developed a preliminary wind farm design, conducted a cost of energy and cash flow analysis for the project life of 20 years, developed a risk management plan, and finalized the detailed design. These completed objectives resulted in a development in the defined region with a rough development plan. The project will be used in the Collegiate Wind Competition through the support of our sponsors: W.L. Gore and Associates, United States Department of Energy (DOE), and the National Renewable Energy Laboratory (NREL). This project is important to our sponsors because it will determine if a wind farm in western South Dakota could be beneficial to the United States.

The origin of where the United States is getting its energy is shifting. This project is a step in producing more renewable energy. Wind energy is expanding and creating more jobs and expecting to increase to produce 35% of the nation's electricity by 2035 [1]. This project is important to prepare students to enter the wind energy workforce by gaining real-world technology experience.

1.2 Project Description

Following is the original project description provided by the sponsor:

> "… The background information about the competition given to the team is: "The competition contributes to the creation and maintenance of American leadership in the transition to a global clean energy economy. Specifically, the competition's objective is to prepare students from multiple disciplines to enter the wind energy workforce by providing real-world technology experience" [2]. The team also has objectives given by the sponsors to create … "a site plan and cost of energy analysis for a 100-MW wind farm" … [2]. The project description given directly from the sponsors gives the team a clear understanding of what is expected to be produced."

2 REQUIREMENTS

To ensure all objectives of the project are completed, the team has created customer and engineering requirements. The customer requirements are made by utilizing the rules and regulations of the competition [2]. Each step outlined in section 2.1 needs to be completed for the project development to meet the competition standards. Engineering requirements are used to ensure all target values of the competition have been reached. These values are either numbers or a yes/no marker.

2.1 Customer Requirements (CRs)

Customer requirements include a wind farm located in the western part of South Dakota that can output a maximum of 100MW of energy. The team needs to produce a site plan with a financial analysis. The information will be presented to a judge panel who understands the design challenge. To accomplish the goals of the project, the team produced a list of customer requirements.

1. Site in Designated Location: The team needs to start the development of the site plan in the designated area (western South Dakota). The site also needs to not be on an existing wind farm or and under-developed one. An explanation of why the site was chosen needs to be explained, for example, wind resource, terrain, landowners, vegetation, access to transmission lines, transportation access, and environmental and community factors.
2. Develop a Preliminary Wind Farm Design: This customer requirement includes drafting a preliminary design, researching site characteristics, and collecting information for permitting. The preliminary design will explain the turbine type, hub height, rotor diameter, and number of turbines the team choses on the project boundary to develop less than or equal to 100MW of power. Local ordinances and sensitive environmental impacts will be researched for the collection of information for permitting.
3. Cost of Energy and Cash Flow Analysis for the 20-Year Expected Project Life: The rules have specified the minimum elements that need to be considered for the cost of energy analysis: initial capital cost, annual operating expenses, net annual energy production, market conditions, financing plan, and incentives.
4. Risk Management Plan: The team needs to consider unknowns, uncertainties, and delays of their project to understand how they affect the financing and manufacturability schedule of the proposed plan. This plan will include, at minimum, a probability of occurrence and consequences of each identified risk.
5. Finalize Detailed Design of the Site Plan: This will be the team's last step and includes collecting wind resource information, contour data, roughness data, turbine locations, site access roads, transmission to nearest substation, and land leases.

All the customer requirements fulfill all the needs of Collegiate Wind Competition, client, and sponsors objectives by either planning the project development or conducting a cost analysis to ensure the project is viable.

2.2 Engineering Requirements (ERs)

The engineering requirements are derived from the Collegiate Wind Competition 2021 rulebook [2]. In this process, the team harmonized the constraints with the engineering requirements to make a successful combination. Each engineering requirement contains a unit, targeting valve, and tolerance level. This method gave a beneficial approach for where to direct the design constraints. All engineering requirements are created to satisfy at least one customer requirement.

2.2.1 ER #1: Accessibility

Accessibility considers how easy the site is to access. This engineering requirement is created for the assigned site location for the best possible layout. In this process, the team considers the site most accessible for the grid line, power station, wind resource, transportation, and grassland terrain. The team will also be assessing the layout of the farm for potential risks.

2.2.1.0 ER #1: Accessibility - Target = Yes

The targeting values is 'yes' for each sector. By reaching a target of 'yes', the accessibility for the sector is adequate. Easy accessibility helps for the siting economics and reduces the total production of the design.

2.2.1.1 ER #1: Accessibility - Tolerance = Not available

The team has not designed a target value for this engineering requirement due to the site either being accessible or not. There is no tolerance for a yes/no marker.

2.2.2 ER #2: Competitive Wind Production

The competition requires energy production to be 100MW or less while making the project as cheap as possible. To satisfy this requirement, the team has researched permitting, ordinances, and zoning from the global level to the local town level. Also, the team will monitor the turbine output power, site characteristics, and best turbine layout.

2.2.2.0 ER #2: Competitive Wind Production - Target = 100MW/year

After gathering more data from the clients and stakeholders during the second semester, the team could identify this approach to design a more successful wind farm that can be competitive with other energy sources by producing around 100MW per year.

2.2.2.1 ER #2: Competitive Wind Production - Tolerance = +/- 10MW

It is impossible to guarantee that the constructed farm will generate precisely 100MW per year due to the weather constantly changing. Also, it is possible to generate higher or lower generation values from the projected simulations. Hence, the team decided to give a tolerance value of +/- 10.00MW.

2.2.3 ER #3: *Levelized Cost of Energy Under 10.00¢/kWh*

The levelized cost of energy is an important factor that has a major effect on the project. The levelized cost of energy is calculated by the System Advisor Model. This cost analysis calculation helps to determine the selling price of the electricity produced by the wind farm.

2.2.3.0 ER #3: Levelized Cost of Energy Under 10.00¢/kWh - Target = 9.00¢/kWh

This target value was created after researching South Dakota's average electricity rates. These values are categorized under three sections: industrial, commercial, and residential. The average wind energy rates for South Dakota industrial at 6.57¢/kWh, commercial at 8.1¢/kWh, and residential at 10.07¢/kWh [3]. To be in the market, the team decided to set a target value under 10.00¢/kWh.

2.2.3.1 ER #3: Levelized Cost of Energy Under 10.00¢/kWh - Tolerance = +/- 1.00¢/kWh

The tolerance value circulates close to the South Dakota average electricity rate, but the team decided not to go beyond that. Also, it is profitless to go above the average value because it can affect the project in the long run, and the consumer can move with different energy-producing projects.

2.2.4 ER #4: *Consistent Wind Speed*

Consistent wind speeds help to maximize the energy production by creating more electricity in the wind turbines. The team is required to choose a site location that has consistent wind speeds throughout the year. Since the team only has one year to work on the project, South Dakota wind maps and Wind Prospector will be used to find this information.

2.2.4.0 ER #4: Consistent Wind Speed - Target = 9.00m/s.

The average annual wind speed of South Dakota is 9.5m/s at 80 meters. Although, usable wind speeds for a wind farm are 5 m/s and above, the team has aimed for a site that has a higher wind speed.

2.2.4.1 ER #4: Consistent Wind Speed - Tolerance = +/-1.00m/s

After generating the wind power analysis results through Wind Prospector at ground level, 80 meters, and 100 meters elevations, the team identified wind speeds circulate around 9.00m/s, so the team decided to use a tolerance level of +/-1.00m/s.

2.2.5 ER #5: *Avoiding Natural and Biological Resources*

The team is needing to avoid natural and biological resources to preserve the environment. Final site plans can affect ecosystems that are critically endangered. To meet this engineering requirement, the team's approach is to build distance from the site to sensitive places through monitoring in Wind Prospector.

2.2.5.0 ER #5: Avoiding Natural and Biological Resources - Target = 50km

Wildlife agencies and services in the area, in addition to using Wind Prospector, helped to collect the needed data regarding sensitive species. Finally, the team decided to put the site location in an environment that has no natural and biological resources within a 50km radius.

2.2.5.1 ER #5: Avoiding Natural and Biological Resources - Tolerance = +/-5.00km

When finalizing the site, the location can have a tolerance of 5km for the 50km radius. Wind resource data and accessibility hold a higher priority, so the site can be closer to the sensitive areas to account for higher priority items.

2.3 Functional Decomposition

One technique the team used to understand the project, was a functional decomposition model. One model is the black box model for the develop and operation of the design. The work-process diagram shows the flow of tasks that were completed to finish the project. An operation and maintenance model shows the post-development breakdown that will need to be completed for safety. The development black box model has become more complex as the project as progressed. More details of the inputs have been included (ex. specific site details and cost objectives). This is because the team gained a clearer understanding of the objectives as the project developed.

2.3.1 Black Box Model

To development a wind farm, the team needed to create a black box model to understand the inputs and outputs of the project. The outputs are the objectives the team needs to reach. Inputs are the values needed to complete the desired output. The model shows the first steps needed to complete the project. To develop the site, the team needs resources to make sure the site will produce energy while still being courteous to the land. To produce energy, the team needs to find a site with good wind and select a suitable wind turbine. At the end of the project, the output signal of the project is whether the project is viable. The project development black box model is shown in Figure 1.

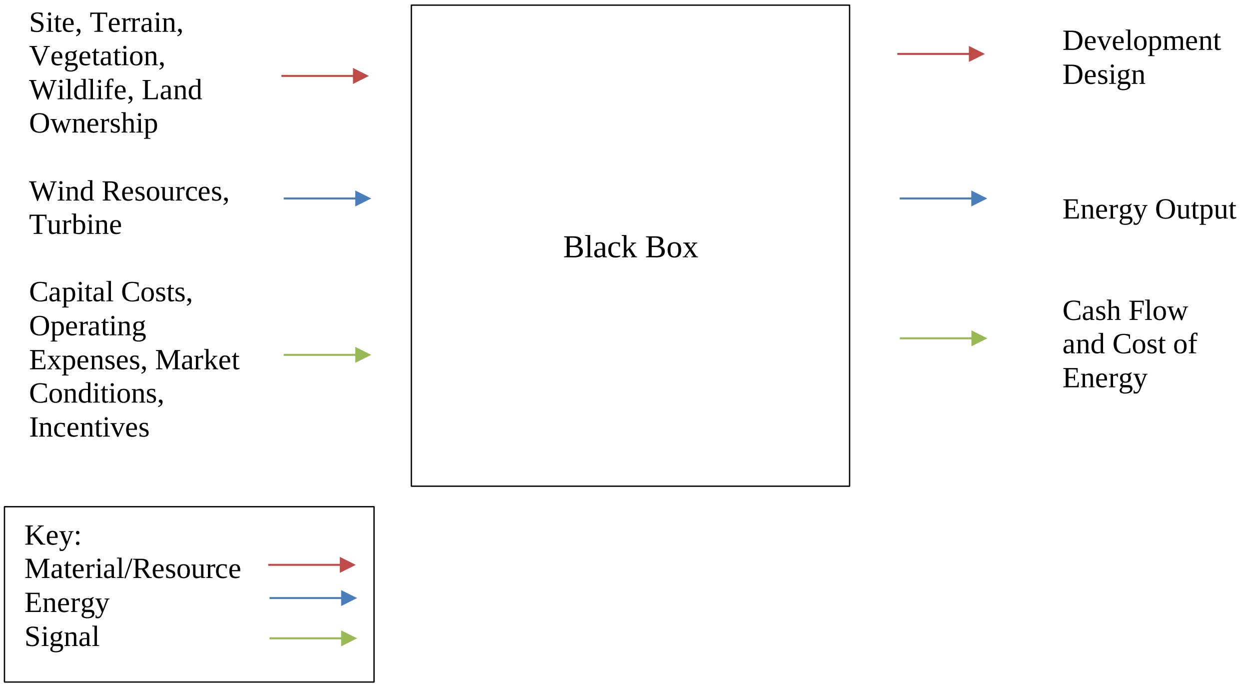

Figure 1: Project Development Black Box Model

Displayed in Figure 2 is the black box model for the operation of a wind farm. The black box model displays the functionality of the wind farm and the different inputs and outputs of the wind farm. Wind, personnel, and the turbine would be considered the main components for the wind farm to function and produce energy. The kinetic and mechanical energy is then converted into electrical energy through the wind farm. A cut-in and cut-out signal is produced when the turbine stalls and starts up. While the wind farm is operating, the turbines would produce sound as a signal output. The wind farm would also receive and external digital signal input to operate.

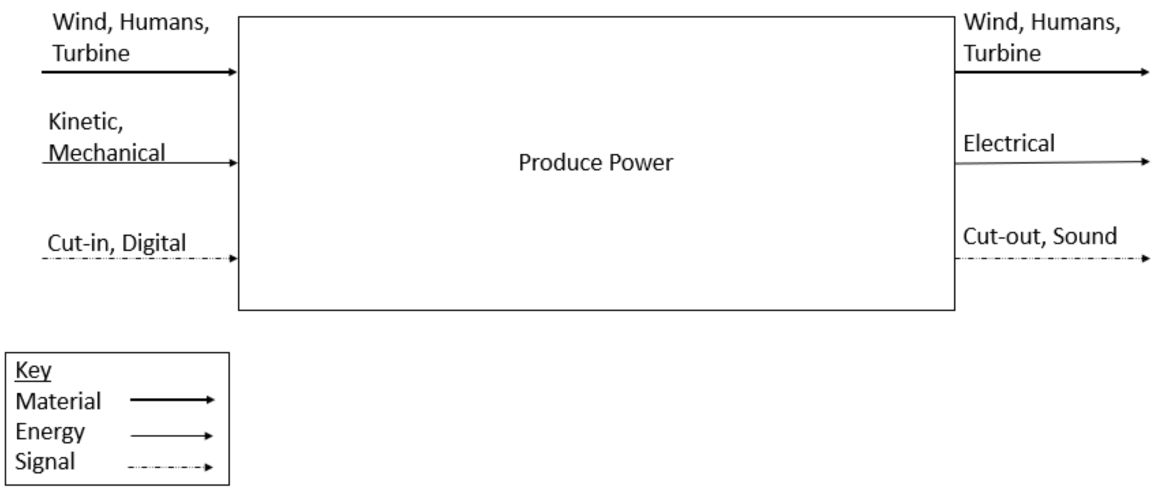

Figure 2: Operation Black Box Model

2.3.2 Work-Process Diagram

Using the project development black box model, the team was able to create a work-process diagram. This diagram shows the breakdown of all the tasks needed to complete all the outputs in the black box model. Figure 3 helps the team visualize all the necessary steps to be successful. The team was able to assign these tasks to members of the team, so everything gets done. Figure 3 clarifies the project for the team by outlining all the steps until completion.

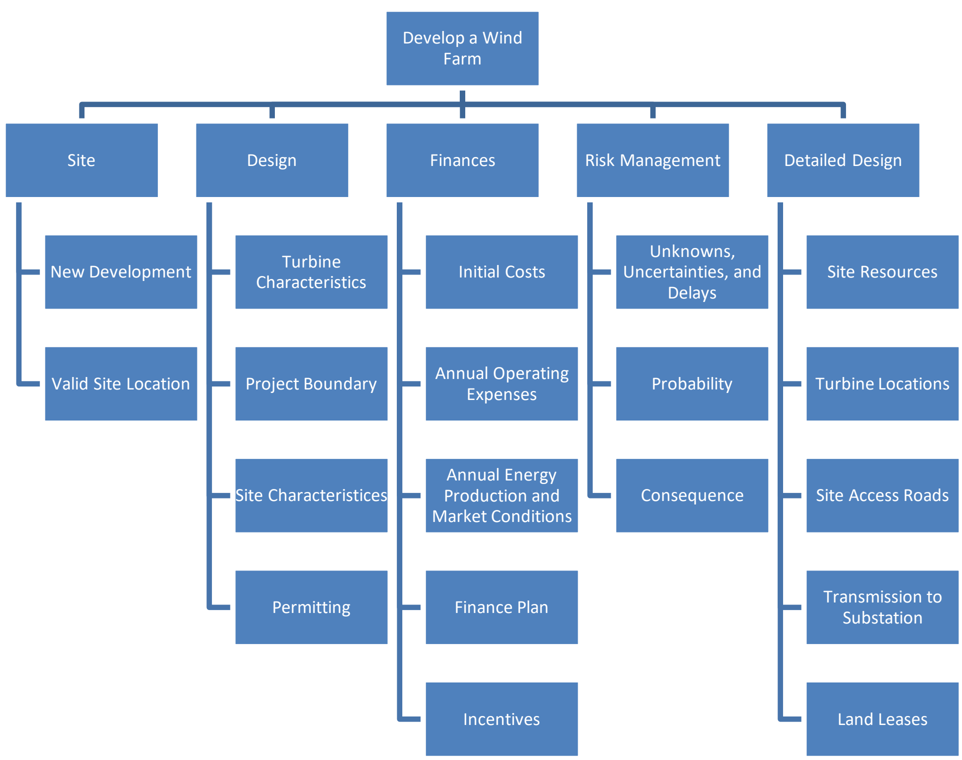

Figure 3: Project Development Work-Process

2.3.3 Operation and Maintenance Functional Model

Figure 4 represents the overall functionality of the operation and maintenance process for the power plant. It focused on the energy and signals that come to the power plant and is exported out of the power plant. As displayed, one of the major inputs for the power plan is the energy generated from the wind.

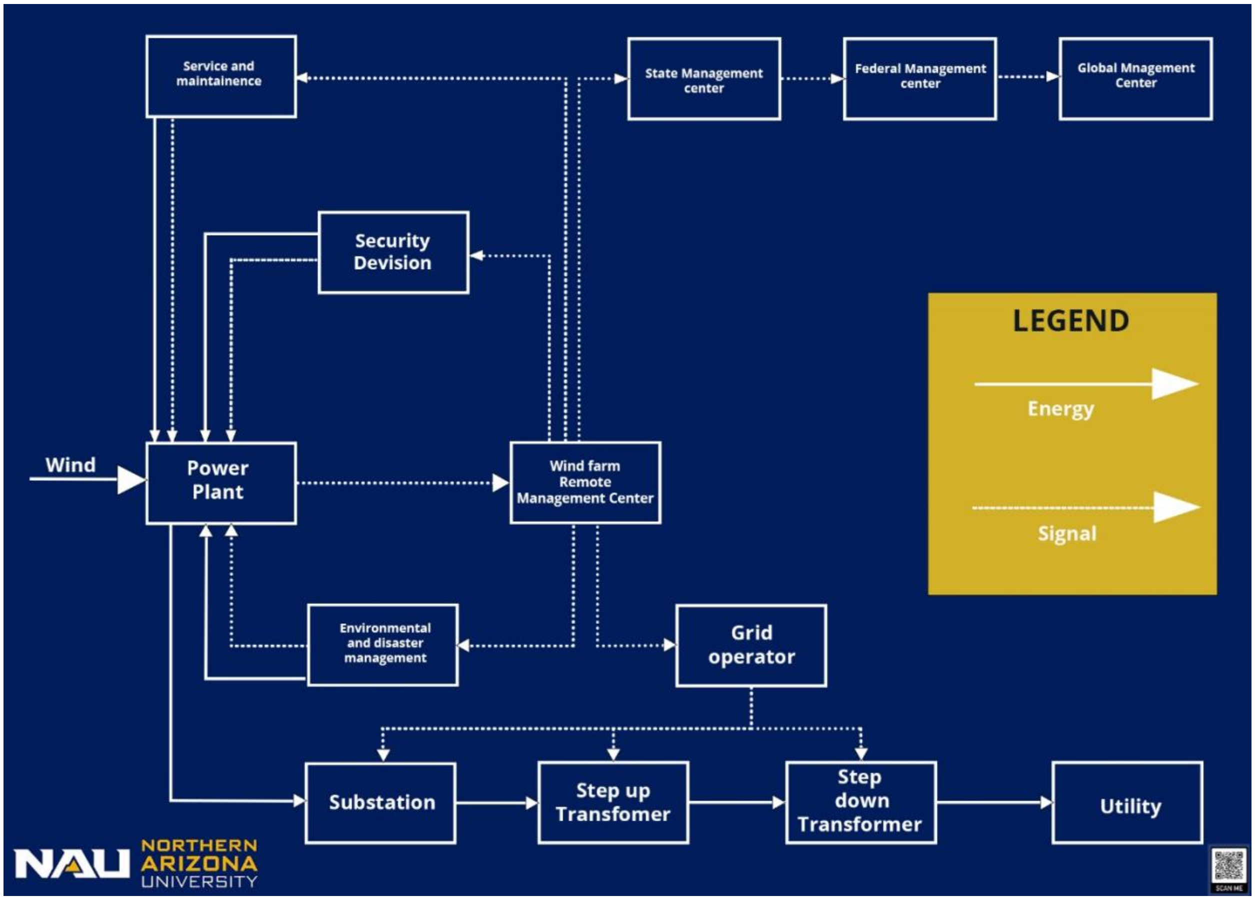

Figure 4: Operation Functional Model

The overall plant is managed by the windfarm remote management center as the central real-time monitoring network hub. The hub has the power to receive the data that comes from the plant as digital signals. The received data would then be analyzed and stored by them for long-term decisions. The hub can also function to operate the whole wind farm in worst case scenarios. The data collection is given to the state, federal, and global government for records of power production. The service and maintenance center, security division, grid operator, and environmental and disaster management center directly link with the central hub to also receive digital signals in worst case scenarios.

The service and maintenance center would monitor the wind turbines and analyze those up to a single level. The maintenance center is responsible for maintaining the mechanical components of the turbine and the consistent lifetime. The grid operator handles the energy from the power plant. The produced energy is sent to the substation and transformers that is hooked to the grid system. The step-up transformer converts this energy into a high voltage to travel long distances. The step-down transformers convert the high voltage back to low voltages for distribution to local communities. The grid operator is responsible for electricity to flow reliably 365 days a year for the customers.

To provide holistic protection for the power plant, Siemens Gamesa security solutions cover plant security, network security, and system integrity. Plant security protects the turbines and cables against unauthorized access. Network security protects the data from cyber-attacks. System integrity security functions prevent the duplication of layout data and information [4]. The environmental and disaster management would monitor the sensitivity of the plant environment and can be prepared for upcoming natural disasters.

2.4 House of Quality (HoQ)

Displayed in Table 1 is the House of Quality that the team constructed to better understand the relationship between the customer requirements and engineering requirements. Through these values, the team was able to design the wind farm with specific priorities. The team deemed that energy production, site suitability, risk management, and the site design were high priorities and were rated respectively. The cost of energy that the wind farm produces, and the 20 year life span is important but is also related to the higher ranked engineering requirements and were ranked with respect to the previous engineering requirements. The tolerances for this HoQ are back in section 2.2 .

Table 1: House of Quality

			Functional Requirements			
		Engineering Requirements	▲	▲	□	
Relative Weight	Customer Requirements	Customer Requirements	Consistent Wind Speed	Accessibility	Levelized Cost of Energy	Terrain Impacts
21%	7	Site Suitability	●	●		●
18%	6	Site Design	○	○		●
6%	2	20 Year Life Span		▽	▽	
21%	7	Risk Management		▽		●
9%	3	Cost of Energy	○		●	
24%	8	Energy Production	●		●	▽
		Importance Rating Sum (Importance x Relationship)	490.91	273	306	570
		Relative Weight	30%	17%	19%	35%

Relationships		Weight
Strong	●	9
Medium	○	3
Weak	▽	1

Due to this project being purely hypothetical and primarily a research based project, the team did not have to create any physical models nor test any physical models. The team however did simulate the final site with different turbine layouts.

2.5 Standards, Codes, and Regulations

The siting project standards and codes are about the effects on the environment, land, and aviation safety. U.S. environmental standards are made to protect the wildlife species. For this project, the team is using private land; hence federal government guidelines and bureau of land management guidelines are not addressing this project [5]. The federal aviation administration is concerned about wind farms that reach above 200m [5]. Therefore, we have to follow the aviation safety guidelines. Table 2 represents the standard numbers and codes the team must follow.

First row shows the standard number or code, title of the standard, and how it applies to the project. Second row represents a joint regulation which is conducted by the United States Fish and Wildlife Services (USFWS) and National Marine Fisheries Service (NMFS) [6]. Prior to starting the design approach, the team had to find and list down the endangered species around the area. Using Wind Prospector, the team found the whooping crane and bald eagle. During the operational period, the team will have to monitor these two spices and consult with the NMFS and USFWS. The mitigation patterns of the whooping crane do not go through the team's site, but the team wants to make sure they are not liable for any accidental passing.

Table 2: Standards and Codes

No	Standard Number or Code	Title of Standard	How it applies to Project
1	50 CFR 424	Endangered and Threatened Wildlife and Plants; Regulations for Listing Endangered and Threatened Species and Designating Critical Habitat	In order to monitor the critical habitats and threatened species, team consulted with NMFS and USFWS about endangered and threatened species within the potential area.
2	P.L. 96-366, 94 Stat. 1322	Fish and Wildlife Conservation Act of 1980	Assist to restore and maintaining the fish and wildlife
3	AC 70/7460-1M	Obstruction Marking and Lighting	Lightning and obstructor indicators help to navigate air crafts, birds, bats and people near wind farm during the night time.

3 DESIGN SPACE RESEARCH

In ME 476C, the team learned about previous designs and conducted research. The literature review provided the team with preliminary knowledge for the project. Journals and reports were used to find accurate information. The team also conducted research into benchmarking for the design space. Information could be found through past successful CWC project developments. Past team's information will be useful during the design of the team's own wind farm.

3.1 Literature Review

During ME 476C, the team had conducted a literature review to gain sources to use for benchmarking as well as the overall design. Market report were used (2018 Wind Technologies Market Report) to determine what the existing wind companies were and the economic position of wind turbines [7]. Permitting requires a lot of action that involved business and politics. There are processes that a development must follow in order to obtain permits and property rights. These documented rights for a large-scale wind farm can be found in handbooks [8]. The market report and handbook have helped the team gain a basic understanding of finances and permitting. To further understand finances, the team learned about the System Advisor Model (SAM) to estimate grid-connected wind farms using the National Renewable Energy Laboratory's open-sourced program [9]. The team also had to conduct research in how to model the performance of the wind farm to meet the competition requirements. Continuum was researched to understand how to model the system accurately using weather and terrain data [10]. To understand transmission line set-up, the Homeland Infrastructure Foundation-Level Data was first researched [11]. This database provided the team with data that can be used to determine if a transmission line is near the desired site [12]. The literature review performed by the team provided basic research that was used in determining if a project site should be developed or if a new site should be found.

3.2 Benchmarking

In this section, past winning teams from 2019 has been evaluated. Through their designs and design changes, the team plans to use this information to better create the current makings of the wind energy plant. By being able to see what past teams have struggled with in the past, the team can focus on these specific areas to avoid future troubles. An extensive research will be conducted once the set variables have been found. The team has done a comparison to how the winning teams have had major changes in their design, and the team will be looking into their own parameters to avoid these troubles in the future.

3.2.1 System Level Benchmarking

In this section, the winners of the CWC development team's design have been researched to see major changes within their own design. The team evaluated the components that were changed and have had a significant impact on the final design.

3.2.1.0 Existing Design #1: Iowa State 2019

Some major design factors that the Iowa State University includes the underground transmission lines, landowners, and accessibility [13]. These criteria relate to the team's original requirements because the team is prioritizing the accessibility to the wind farm along with the distance from transmission lines. The team has also selected ideal sites that are not protected, already have an energy farm, and occupied/private areas. It is important to investigate the landowners themselves due to the wind energy farm being built upon the land others may own. Transmission lines also play a major role in being able to create a wind energy farm because having to build another transmission line that would connect to a main transmission line would cause the budget of the project to increase from the desired amount.

3.2.1.1 Existing Design #2: Pennsylvania State University 2019

The main design that Pennsylvania State University underwent was the location in which they have decided to place their wind energy farm [14]. The team also had to worry about environmental impacts their wind energy farm would produce [14]. Pennsylvania State University's team had the same major factor as Iowa State University with the location of their wind energy farm. NAU's CWC team will later have a major evaluation of owners of the western part of South Dakota. Pennsylvania State University's team has brought up a major factor that NAU's team has yet to factor into the placement. The team will research this subject soon.

3.2.1.2 Existing Design #3: Virginia Tech University 2019

Some of the major design components that Virginia Tech University had included the roads that were going to be used to create the overall wind energy plant and the layout of the wind energy plant itself [15]. With transportation being a major factor in creating the energy plant, the team has considered transportation to be important but has not made this one of our major parameters due to the team prioritizing the placement of the wind energy farm. The layout of the wind energy is important as Virginia Tech University has found it to be, the team is experimenting with these parameters and will thoroughly research the array parameter.

3.2.2 Subsystem Level Benchmarking

In this section, some smaller factors that have had a major effect on previous CWC 2019 team winners' final design are being evaluated.

3.2.2.0 Subsystem #1: Location

Location of the wind energy farm has a major factor in energy generation due to the wind speed that different areas receive along with the factor of the roughness that the turbines would be situated on. The location also needs to be near the transmission lines.

3.2.2.0.1 Existing Design #1: Iowa State 2019

Although Iowa State University has had trouble with their own placement of the wind energy farm, the location that have chosen is the best for their specific design. Iowa State specifically worried about the distance from the ground to the transmission line [13]. By having this parameter, the team is aware that the energy farm cannot automictically be connected to the transmission lines, but it is still important to consider the distance from ground level to the transmission line that would be located underneath the transmission line.

3.2.2.0.2 Existing Design #2: Pennsylvania State University 2019

Pennsylvania State University also struggled with where specifically to place their wind energy farm but were able to find the ideal placement for their own specific wind energy farm. The location of their wind energy farm specifically had troubles with land ownership and had to rethink of where to locate the wind energy farm due to the land being divided by owners [14]. The team will be able to evaluate the location of the wind energy farm after fully evaluating the western part of South Dakota.

3.2.2.0.3 Existing Design #3: Virginia Tech University 2019

It has been found that Virginia Tech University did not put much thought into having a beneficial location.

3.2.2.1 Subsystem #2: Energy Generation

Energy generation is important to the system due the wind farm having to produce energy that is marketable. With more energy being produced, it is projected that the price for the electricity can be lowered and be considered bankable.

3.2.2.1.1 Existing Design #1: Iowa State 2019

Following the trend of the CWC, Iowa State aimed to make 100 MW Wind Farm. This farm was to be placed within 100 miles of their school utilizing 161 and 345 kV transmission lines. The annual energy production estimate for the project turned out to be 438,602.09 MWh.

3.2.2.1.2 Existing Design #2: Pennsylvania State University 2019

The Penn State team was looking at three different turbines to determine the overall power output for the different wind speeds withing places around Pennsylvania State. They were looking at turbines at different hub heights from Alstom ECO turbines. The turbines that were being used were rated for 3MW and 2.7 MW outputs. They also found the ideal number of turbines for creating a 100 MW wind farm.

3.2.2.1.3 Existing Design #3: Virginia Tech University 2019

The Virginia Tech team decide to do a GE 4.8-158 turbine. It is a new turbine, but it was chosen because its ability to generate power at low wind speeds. It is in the Floyd County Virginia off the side of route 730. The site has a rated capacity of 100.8 MW, the net annual rating is expected to be 279.67 GWh per year.

3.2.2.2 Subsystem #3: Cost Analysis

Cost Analysis is a major role in the creation of the wind energy farm to see if the amount of money spent would benefit the future income that the wind energy plant will bring in.

3.2.2.2.1 Existing Design #1: Iowa State 2019

Iowa State University has found that over a 10-year period, the total amount of money produced would be around $33 billion but to create the energy plant would take around $157 billion [13]. The team is aware that constructing the wind energy farm may be more costly than the actual income that the wind farm can generate.

3.2.2.2.2 Existing Design #2: Pennsylvania State University 2019

According to Pennsylvania States University report, it has been found that their total design would be around $175 billion while the total amount income would be around $12 billion [14]. The team is factoring cost analysis into the wind turbine and is aiming to create if possible, a lower cost energy plant while being able to create a high-income energy plant. With the creation of this kind of plant not only would the community benefit from the lower cost of energy but would also be able to not have to worry about going into debt.

3.2.2.2.3 Existing Design #3: Virginia Tech University 2019

In Virginia Tech University's report, the total cost of creating the wind energy plant is around $185 billion plus extra bills due to land leases, maintenance, operations, and administrative and legal expenses turn out to be $2 billion [15]. Although the report does not specifically state the total amount of income within 10 years, it has been found that their wind energy plant would help the locals by producing 40% of the local's energy [15]. The team will consider and is still aiming to create a low-cost energy wind turbine while having the plant have a high income.

4 CONCEPT GENERATION

Using the information collected in the benchmarking for the siting project development, the team was able to start concept generation. Six potential wind farm sites were found using the engineering requirements and customer needs. The black box model and functional decomposition started the process to identify what is needed for a successful design. These potential sites provide the team to start analysis to find the best concept for the project.

4.1 Full System Concepts

These six sites were selected with the engineering requirements and customer needs accounted for. There were originally 19 sites that were mapped out on Google Earth. These 19 sites were decided upon because of their ideal wind speeds ranging from 8-9 m/s at a height of 80 meters. Transmission lines, cities and counties, restricted areas, and manufactures were mapped out in the region to see which sites would provide the team with the best option. Those 19 sites were originally brought down to 6 sites based on transmission line proximity which is a necessity for the success of the project.

4.1.1 Full System Design #1: Site 3

Site 3 is in Perkins County, South Dakota. It is not far from transmission line 220-287. The site could be expanded to reach the transmission line if this site is chosen. This is a negative about the site. The main disadvantage of the site is how close it is to a restricted area the team has mapped. The restricted area is the State Experiment Farm and Antelope Reserve that is in Reva, South Dakota. There are also no big cities or warehouses near the site that the wind farm could provide direct power to. The positive of this site is the potential to connect to a transmission line. Perkins County is on the north edge of South Dakota with the nearest transmission line connecting to North Dakota. This would allow the team to have a potential opportunity of providing power to North Dakota.

4.1.2 Full System Design #2: Site 7

Site 7 is also located along transmission lines 220-287. The site is located along the edge of Perkins County and Meade County. There is plenty of room to build a wind farm because there are no restrictive areas around the site. While there are no big cities or warehouses directly near Site 7, it can provide energy to bigger cities like Rapid City through the transmission line. This could be a positive as it would ensure the site is not an inconvenience to a bigger population while still providing needed energy.

4.1.3 Full System Design #3: Site 10

Site 10 is very similar to site 7. It is located along the 220-287 transmission lines. It is a little south of site 7 located only in Meade County. This option is closer to Rapid City where the energy could be transported to. There are no warehouses that the power could be used for around site 10. Its closer proximity to Rapid City does provide a positive part of this site selection. There also is room for a wind farm since there are no restrictive areas nearby that limit the available space to use.

4.1.4 Full System Design #4: Site 11

South of site 10 is site 11 also in Meade County. Site 11 is a little off to the right side of transmission lines 220-287. It is a lot closer to Rapid City and smaller cities surrounding the area. This would be a benefit of this chosen site. Since it is closer to larger cities, that leads to one negative of the site. Even though there are no restrictive areas nearby, the space is limit due to a larger population surrounding the site. This could lead to not enough power being generated from the wind farm than the required 100-MW.

4.1.5 Full System Design #5: Site 12

South of site 10 is site 11 also in Meade County. Site 11 is a little off to the right side of transmission lines 220-287. It is a lot closer to Rapid City and smaller cities surrounding the area. This would be a benefit of this chosen site. Since it is closer to larger cities, that leads to one negative of the site. Even though there are no restrictive areas nearby, the space is limit due to a larger population surrounding the site. This could lead to not enough power being generated from the wind farm than the required 100-MW.

4.1.6 Full System Design #6: Site 19

Site 19 is in Fall River County which is also far from the major city of Rapid City. Fall River County does have a larger population than Haakon and Perkins County. There are no big warehouses near the area either that the power could be transported to. The main positive of site 19 is the proximity to multiple lines of the transmission lines 220-287. Both lines go through Rapid City, so the power could be delivered through the transmission lines 220-287 the easiest. Site 19 is closer to one of these lines but could be connected to the other line to deliver power to multiple areas. Fall River County is on the south-left border of South Dakota. The transmission lines site 19 could connect to would allow for a potential delivery of power to Wyoming and Nebraska.

4.2 Subsystem Concepts

Using the Black Box Model and Functional Model to understand the subsystems needed for the project, the team has created five full-system concepts for the three subsystems. Using the counties and cities that are close to transmission lines, the team decided on a couple potential locations. If these locations are not close to transmission lines, they are close to a larger portion of the South Dakota population where the energy will be most used. These locations were one of the first steps of finding a location, as well as considering restrictive areas and nearby manufacturers. After a location is picked using objective figures and a Pugh Chart and Decision Matrix, the next step to analyzing the energy generation of the site is to pick an effective commercially available wind turbine. These turbines need to be effective at the hub height with respect to the wind speeds at that height. After a turbine is picked, the site can be modeled using Continuum and System Advisor Model. The turbines selected are from the manufacture Siemens Gamesa because those are the closest manufactures near the potential sites. Once all the details about location and turbine selection are decided upon, the last step the team needs to do is analyze the cost of the development.

4.2.1 Subsystem #1: Location

The location of the site can affect the wind farm in different ways including obtaining different permits, abiding by different laws, and community guidelines.

4.2.1.0 Design #1: Perkins County

Perkins County is along the top left side of South Dakota. The population is 2,982 people. The downside of this site is the low population with no nearby warehouses or big population. The location is next to transmission lines 220-287 that can deliver the power to surrounding areas. Since the county is close to North Dakota, there is a potential to send energy to counties in North Dakota.

4.2.1.1 Design #2: Meade County

Meade County is located south of Perkins County. The population size is 25,434 people with the transmission lines 220-287 running through the county. The county is much bigger than Perkins County. This makes the location a better option for direct energy options. There are no big warehouses in the county which is a downside. The county is closer to a bigger city, Rapid City, which makes the county more valuable.

4.2.1.2 Design #3: Haakon County

Haakon County is in the middle of western South Dakota with a population size of 1,937 people. This is one of the smaller counties that is located along transmission lines 220-287. This makes the county less valuable since there are no big populations or warehouses for the energy to be directly delivered to. Since the county has transmission lines 220-287 through the county, the energy can be sent to other areas nearby.

4.2.1.3 Design #4: Fall River County

Fall River County, located in the bottom left-hand side of South Dakota, has a population of 7,094 people. This is the second largest county that has good areas for a wind farm. The county is also a good choice because there are multiple lines of the transmission lines 220-287 located in the county. This will provide multiple options of where the generated energy could be delivered. The only downside of this county is the small population with no big warehouses.

4.2.1.4 Design #5: Rapid City

Rapid City is the largest city in western South Dakota with a population of 75,443 people. This population would be the ideal area for the power to be delivered. Unfortunately, a wind farm cannot be placed here because there is not enough room to put a wind farm in a heavily populated area. While the site for the project cannot be placed here, the team will try to make sure energy can be delivered to this population.

4.2.2 Subsystem #2: Energy Generation

Energy generation is an important part of developing the wind farm. Not only would the turbines be experiencing different outputs but would also be at different heights that can give the team different energy production values.

4.2.2.0 Wind Turbine #1: SG 5.0-132 at 84 meters

One of the turbines selected from Siemens Gamesa is the SG 5.0-132. The rated power is 5.0 MW per turbine with a wind class of IEC IA. The turbine can be controlled using pitch and variable speed. With the location of the wind farm in western South Dakota, the standard operating temperature of –20 degrees Celsius to 45 degrees Celsius will be a good fit. The lowest temperature during the winter months in western South Dakota occur at around –16.5 degrees Celsius. If the operating temperature could perform at a lower temperature, it would make the turbine a litter better of a selection. The length of the blades for this turbine is 64.5 meters. The hub height of 84 meters will reach the wind speeds of 8-9 m/s that the potential sites were selected at. This turbine is a great middle-class selection that would be a good choice.

4.2.2.1 Wind Turbine #2: SG 5.0-145 at 90 meters

The SG 5.0-145 is another option from Siemens Gamesa. With a wind class of IEC IIB, the rated power is 5.8 MW per turbine. This selection also uses pitch and variable speed to control the turbine. Standard operating temperature is also –20 degrees Celsius to 45 degrees Celsius which does not make the turbine more valuable in this aspect. The blade length is 71 meters which is longer than the SG 5.0-132 to create the extra 0.8 MW of power. More area would be needed to compensate for the larger size. The hub height is at 90 meters to be able to reach the wind speeds needed for the project.

4.2.2.2 Wind Turbine #3: SG 5.0-145 at 102.5 meters

The SG 5.0-145 at 102.5 meters is the same model as Wind Turbine #2, but the tower is taller. The hub height in Wind Turbine #3 is 102.5 meters. This turbine would allow the turbine to reach faster wind speeds to increase energy generation. The blade length is the same as the lower height turbine, so it would require the same amount of space of 16,513 m^2. All the design details are the same as Wind Turbine #2, but the higher hub height allows for the potential to create more energy.

4.2.2.3 Wind Turbine #4: SG 3.2-132 at 84 meters

SG 3.4-132 is another model from Siemens Gamesa that the team is considering. It is lowest rated power of 3.465 MW per turbine. It has a wind class of IA/IIA that controls the turbine using pitch and variable speed. The standard operating temperature is a smaller range of –20 degrees Celsius to 30 degrees Celsius. Unfortunately, this wind turbine selection does not perform under –20 degrees Celsius, which does not make this turbine a better selection. Wind Turbine #4 has a hub height of 84 meters and a blade length of 64.5 meters. This is a positive of the model because it can reach the 8-9 m/s wind speeds of the potential sites.

4.2.2.4 Wind Turbine #5: SG 3.2-132 at 108 meters

The last potential wind turbine the team has investigated is the SG 3.2-132 at 108 meters. This is the same model at Wind Turbine #4, but with a taller tower of 108 meters. This would allow the turbine to reach faster wind speeds at the site, while still only needing 13,685 m^2 of area for a turbine. This would be a good option to increase the power the site could generate with a taller hub height. This option would produce less power than Wind Turbine #3, but it needs less space. Less space needed would allow the team to use this turbine in smaller areas.

4.2.3 Subsystem #3: Cost Analysis

With the requirement to make the wind farm as cheap as possible the team is going to perform multiple financial analysis models.

4.2.3.0 Analysis #1: System Advisor Model (SAM)

While the first decision the team will be making is site location, SAM can be used to determine the cost analysis. SAM can model renewable energy plants like wind farms. Some of the information the team can use form SAM is state income tax numbers that can validate the construction of the wind farm. Data tables will also be calculated once the development is modeled. These models show basic outputs of energy generation. There is another section called Cash Flow that analyzes financial calculations for the plant. The Cash Flow section will be the most valuable section for cost analysis. The downside of SAM is how it does not show specific details of how the state and city will be affected by the wind farm.

4.2.3.1 Analysis #2: Jobs and Economic Development Impact Model (JEDI)

JEDI can provide more details to how a wind farm affects the surrounding area compared to SAM. When JEDI is run, it can predict the impacts from construction and operating power generation. It can also show on-site labor and services that will be needed. JEDI will analyze potential local revenues with the supply chain included. A positive of JEDI is the ability for the software to analyze both short-term and long-term periods. SAM does provide more energy analysis with income taxes that JEDI does not analyze. This is a downside of JEDI.

4.2.3.2 Analysis #3: Continuum 3

Continuum 3 uses on-site measurements to model wind flows. It will be an essential software for the team to model energy production. The software also does wake loss modeling, net energy, that will show the team energy production losses. Another positive of the software, is its ability to evaluate site suitability and can also show the feasibility of the project. The downside of this software is that there is no information of the costs of the project and how it affects state and city economies. This software would have to be used in a combination of other software for the team to complete a full cost analysis.

4.2.3.3 Analysis #4: Cost-Benefit Analysis

If the team decided to do the calculations by hand, a cost-benefit analysis could be performed. To complete this the team would list out all the benefits of the project (ex. parts, labor, revenue, etc.) with its relative cost. This analysis is a great start to get an idea if the development is viable, but this should not be the only cost analysis performed. Compared to the other analysis options for the subsystem this option does not provide as much information. There would be lost information about state and local economies, as well as understanding the manufacturing costs.

4.2.3.4 Analysis #5: Life-Cycle Cost Analysis

Life-cycle cost analysis is another hand calculation that can be performed. It is straightforward interpretation of the economic evaluation of a project. The team would add up the initial cost, replacement costs, residual value, desired life, total energy costs, maintenance costs, operating costs, and other costs such as salaries and benefits. The addition of these costs would give the team the total life-cycle cost in present value dollars. This is a simple analysis step the team could perform, but it will not be as accurate as Analysis #1, #2, and #3.

5 DESIGN SELECTED – First Semester

The siting team has used multiple tools to narrow down the best sites that the team has generated at the beginning of this project. With the various evaluations that the team has used to generate and narrow down potential designs, concepts, and designs, the team is left with ideal designs, concepts, and sites. By using Pugh Charts and Decision Matrices, the team was able to narrow down and develop a main concept design. Through the usage of the chart and matrix, the team was also able to evaluate sites, concepts, and designs. For this project, the team did not have to perform many calculations in the first semester.

5.1 Concept Selection Criteria

The concept selection criteria are the process of selecting the best location for the wind farm. Since the design does not exist yet, the team had to come up with a total of six sites. Hence, there is uncertainty in which site is the ideal. In order to that, the team used two criteria to compare the selected six different sites. Gathered site locations entered a Pugh chart (Table 3) to eliminate based on customer requirements and output results compared to the datum. In the second criterion, the team used a decision matrix (Table 3) to compare all sites to each other based on qualitative measures.

Table 3: Siting Project Development Pugh Chart

Customer needs	Datum Site 7	Site 3	Site 10	Site 11	Site 12	Site 19
Transmission Lines	0	-1	0	0	-1	1
20 years of life span	0	1	0	-1	1	1
Wind Speed	0	0	0	0	0	0
Energy Generation	0	-1	0	-1	1	1
Minimal area	0	-1	1	1	1	0
Levelized cost of energy	0	-1	0	1	1	1
Total points	0	-3	1	0	3	4

Legend
+1 better than datum
0 exact to the datum
-1 worse than datum

By accurate evaluation of the wind speed in South Dakota, the team decided select site locations that would perform best. The first column of the Pugh chart represents the customer requirements that create by the team and accept by David Willy, team's advisor. The second column represents the datum which was site nine. After comparing each site location with the datum, the team found sites 12 and 19 are better. Also, the rest of the sites are weaker. Yet the team did not know, the weak sites can be improved. Hence, the team entered all site locations into the decision matrix.

Table 4: Siting Project Development Decision Matrix

Engineering Requirements	Weight%	Site 7	Site 3	Site 10	Site 11	Site 12	Site 19
Consistent wind Speed	30	1	1	1	1	1	1
Accessibility	10	0	0.5	0.5	1	0	1
Distance to Transmission Line	20	0.5	0	0	0	0	0.5
Terrain quality	15	1	1	1	0	1	0
Energy production	25	0	0.5	0.5	1	1	1
Score	100	55	62.5	62.5	65	70	75

Legend
1 meet the standard
0.5 meet half of the standard
0 doesn't meet the standard

The decision matrix helped the team to eliminate infeasible site locations that produced by the Pugh chart. The major difference between the Pugh chart and the decision matrix is the scoring with more detail. The first column represents the quantitative engineering requirements and each site location scored on that. The team gave specific weight for each engineering requirement appropriately because some engineering requirements more important than others. weight scoring is shown in second column. The consist of wind speed has a high weight because to satisfy the consumer needs, we must expect the same wind speed on the entire year. Accessibility has low weight because in order to satisfy the customer needs it gives less contribution. After summing up the weighted scores for each requirement, the highest-scoring site 19 specified as the best choice to carry further.

6 IMPLEMENTATION – Second Semester

For the remainder of the Spring 2021 semester, the team was able to make progress on the current wind farm iteration. This includes changing the turbines, changing the final site location, and changing the turbine array.

6.1 Design Changes in Second Semester

The general design for this project has been altered by changing the site location, turbine selection, and turbine array. By editing these design changes, the team can produce a better energy output along with lowering the cost of the project for buying turbines and land usage.

6.1.1 Design Iteration 1: Change in Site location

The site that the team originally had planned was in the range of 1000 acres for the 100MW wind farm. The current and final location of the site has around 1200 acres of land that can be possibly used for the wind farm. By having a bigger plot of land, the team plans to space out the wind turbines so wake losses would not be a major factor while still being able to produce energy. The final location only has one landowner and would therefore make it easier for the team to contact and create a hypothetical lease. The wind resource at this location is also higher than the last location the team was looking at.

6.1.2 Design Iteration 2: Turbine Selection

The team has narrowed down some turbines that can be used for the wind farm. Currently the team aims for a bigger turbine and would need to do iterations with regards to seeing which turbine would be the cheapest to use and output the most energy. With the average wind speed at 80 meters being around 9.175 meters per second, the team knows that the turbine that is needed needs to be in the class of 1A for the wind speed. The final turbines that were selected after speaking to industry professionals and analyzing turbines currently being manufactured, the team has decided on the SG5.8-155 turbine.

6.1.3 Design Iteration 3: Turbine Array

The team has narrowed down some turbines that can be used for the wind farm. Currently the team aims for a bigger turbine and would need to do iterations with regards to seeing which turbine would be the cheapest to use and output the most energy. With the average wind speed at 80 meters being around 9.175 meters per second, the team knows that the turbine that is needed needs to be in the class of 1A for the wind speed. The team does not yet know the turbulence that will be experienced at this height which is the reason why the team has yet to narrow down to 1A or 1B. The final turbine is currently being used for current simulations.

7 RISK ANALYSIS AND MITIGATION

In a wind farm, there are failures that could cause damage to the success of a project. When those failures are addressed, the failure can be mitigated. Mitigating the risk of failures can help the project produce the correct amount of power as designed, as well as assist in operation and maintenance. If failures are not mitigated, the project life can be cut short, or the project development will not produce the amount of energy that is required. Risk analysis and mitigation is important to the success of the team's project development.

The team was able to mitigate potential failures by learning about them and implementing instructions on how to resolve the conflict. These instructions included a regular maintenance schedule and thorough design process.

7.1 Potential Failures Identified First Semester

In ME476C, the team created a FMEA to evaluate all the potential failures of developing a wind farm. The top 10 failures are highlighted. During ME486C, these failures were addressed through the mitigation process outlined in Table 5. The full FMEA in Appendix A: Full First Semester FMEA shows a more complex overview. The top 10 failures the team tried to mitigate were watersheds, agricultural production, poor array, improper modeling, lack of incentives, not viable, expensive power, wind above 22 m/s, hurricanes, and tornadoes.

Table 5: Shortened Project Development FMEA - First Semester

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
Location	Not in South Dakota	Wrong location	Planning error	10	Revise Google Earth
	Not close to transmission lines	No project potential	Planning error	9	Revise Google Earth
	Energy availability	No energy potential	Poor energy modeling	32	Pick new site
	Watershed	Negative environmental impact	Lack of research	150	Reach out to industry professionals
	Transportation of materials	Construction obstruction	Lack of outreach	75	Reach out to industry professionals
	Employee proximity	Construction obstruction	Lack of outreach	84	Revise Google Earth
	City proximity	No location to send energy	Poor Google Earth modeling	56	Revise Google Earth
	Endangered animals	Negative environmental impact	Lack of research	60	Reach out to industry contacts
	Endangered fauna	Negative environmental impact	Lack of research	100	Reach out to industry contacts
	Agricultural production	Negative economy impact	Poor Google Earth modeling	144	Increase research and contact outreach

Energy Generation	Less than 100MW of power	Does not meet requirement	Poor modeling	60	Pick new site
	Not enough power for population	Not enough supply	Improper planning	72	Population assessment
	Too much power for population	Unused energy	Improper planning	36	Population assessment
	Poor turbines	Low energy potential	Lack of research	96	Reach out to industry contacts
	Poor array	Inefficient energy	Inefficient energy design	144	Reach out to faculty advisor
	Land availability	Not enough space required	Poor Google Earth modeling	36	Pick new site
	Land permits	Minimum space allowed	Lack of outreach	70	Reach out to industry contacts
	Poor wind speed	Low energy potential	Poor data files	56	Increase research
	Poor consistency	Not enough energy	Poor data files	96	Increase research
	Improper modeling	Inaccurate energy generation	Lack of research and outreach	225	Reach out to industry contacts
	No government support	Overall increase project costs	Lack of research and outreach	120	Reach out to industry contacts
	No city support	Overall increase project costs	Lack of research and outreach	120	Reach out to industry contacts
Cost	Lack of incentives	No tax breaks	Lack of research and outreach	210	Reach out to industry contacts
	Low quality	Decrease in life	Lack of research on wind farms	84	Project assessment
	Too expensive for area	Decrease in life	Lack of research on SD	63	SD assessment
	Not viable	Costs > Benefits	No finance knowledge	280	Reach out to business department
	Can not be maintained	Decrease in life	No maintenance knowledge	45	Run JEDI
	High turbine cost	Increase expenses	Lack of outreach	32	Reach out to industry contacts

	Expensive power	Can't provide power to areas	Poor modeling and finance knowledge	140	Run JEDI
	High construction cost	Increase in construction cost	No maintenance knowledge	64	Run JEDI
	Inconsistent	Energy production	Poor wind data	120	SD assessment
	Available below hub height	Can't obtain energy	Poor location	28	Increase research on SD wind data
Wind	Available above hub height	Can't obtain energy	Poor location	28	Increase research on SD wind data
	Below 6 m/s	Energy production	Poor location	18	Increase research on SD wind data
	Above 22 m/s	Safety hazard	Poor location	135	Increase research on SD wind data
	No energy potential	Incomplete goal of project	Not enough wind at location	60	Pick new site
	Hurricanes	Safety hazard	Environment	144	SD assessment
	Tornadoes	Safety hazard	Environment	168	SD assessment
	No wind data	No siting development	Lack of research	60	Reach out to faculty advisor
	Seasonal winds	Seasonal energy production	Environment	80	SD assessment

7.2 Potential Failures Identified This Semester

A wind turbine is comprised of the main components: blades, generator, gearbox, and tower. All these components have risks of failure. Blade failure is a common concern in a wind farm. Blade sizes can be increased to produce more power, but bigger blades create more stress on the turbine structure [16]. Generator failure can also occur. The generator is important because it converts the mechanical energy created from the wind turbine into electrical energy. A failing generator will not create any power for the development [16]. Gearbox failure is very expensive when it occurs. It is expensive to replace and will cause the shutdown of the turbine. Many causes can create the potential of a gearbox failing. The tower encloses the cables of the turbine. Inclement weather can cause damage to the tower, therefore, damaging the cables. All the failures that can cause these components to become damaged are listed in Table *6*. The full FMEA is provided in Appendix B: Full Second Semester FMEA.

Table 6: Shortened project Development MEA - Second Semester

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
Blade	Wear	Flying Debris	Debonding	24	Preventative Maintenance
	Wear	Flying Debris	Joint Failure	24	Preventative Maintenance
	Wear	Flying Debris	Splitting Along Fibers	24	Preventative Maintenance
	Wear	Flying Debris	Gel Coat Cracks	36	Preventative Maintenance
	Wear	Flying Debris	Erosion	45	Preventative Maintenance
	Inclement Weather	Loss of Function	Lighting Strikes	28	Preventative Maintenance
	Production Failure	Flying Debris and Loss of Function	Material or Power Regulator Failure	18	Preventative Maintenance
	Impact	Flying Debris	Damage from Foreign Objects	40	Preventative Maintenance
	Production Failure	Loss of Function	Poor Design	16	Preventative Maintenance
	Production Failure	Loss of Function	Poor Maintenance	36	Preventative Maintenance
Generator	Inclement Weather	Loss of Function	Wind Loading	15	Maintenance and Repair Program
	Inclement Weather	Loss of Function	Weather Extremes	48	Maintenance and Repair Program
	Wear	Loss of Function	Thermal Cycling	36	Maintenance and Repair Program
	Wear	Loss of Function	Mechanical Failure of Bearing	18	Maintenance and Repair Program
	Design Flaw	Loss of Function	Excessive Vibration	24	Maintenance and Repair Program
	Operation Flaw	Loss of Function	Voltage Irregularities	24	Maintenance and Repair Program
	Design Flaw	Excessive Heat and Fire	Cooling System Failure	30	Maintenance and Repair Program
	Design Flaw	System Breakdown	Manufacturing Faults	56	Maintenance and Repair Program
	Design Flaw	System Breakdown	Design Faults	16	Maintenance and Repair Program
	Assembly Fault	Loss of Function	Improper Installation	75	Maintenance and Repair Program
	Assembly Fault	System Breakdown	Lubricant Contamination	32	Maintenance and Repair Program
	Design Flaw	Loss of Function	Inadequate Electrical Insulation	40	Maintenance and Repair Program

Gearbox	Design Flaw	System Breakdown	Design Life	210	Preventative Maintenance
	Wear	System Breakdown	Mechanical Failure of Bearing	48	Preventative Maintenance
	Wear	System Breakdown	Mechanical Failure of Gears	36	Preventative Maintenance
	Assembly Fault	System Breakdown	Dirt Contaminated Lubrication	48	Preventative Maintenance
	Assembly Fault	System Breakdown	Water Contaminated Lubrication	27	Preventative Maintenance
	Assembly Fault	Loss of Function	Improper Bearing Settings	32	Preventative Maintenance
	Design Flaw	Loss of Function	Temperature Fluctuations	60	Preventative Maintenance
	Poor Maintenance	Loss of Function	Improper Maintenance	64	Preventative Maintenance
	Poor Maintenance	Loss of Function	Infrequent Maintenance	60	Preventative Maintenance
	Wear	Sudden Accelerations and Load-Zone Reversals	Transient Loads	20	Preventative Maintenance
Tower	Assembly Fault	Loss of Function	Assembly Errors	12	Preventative Maintenance
	Poor Maintenance	Loss of Function	Improper Maintenance	6	Preventative Maintenance
	Design Flaw	System Breakdown	Poor Tolerancing	75	Preventative Maintenance
	Design Flaw	System Breakdown	Overstressing	30	Preventative Maintenance
	Inclement Weather	System Breakdown	Tornadoes	80	Preventative Maintenance
	Wear	Loss of Function	Erosion	48	Preventative Maintenance
	Impact	Loss of Function	Animal Destruction	2	Preventative Maintenance
	Impact	Loss of Function	Damage from Foreign Objects	8	Preventative Maintenance

7.3 Risk Mitigation

The risks found in ME 476C were mitigated during the design process. The development was sited in a place where it would not affect watersheds and agriculture. The array design of the turbines was evaluated to maximize the power output, and to ensure modeling was done correctly, the instructions were followed as well as using guidance from the program developer. The team was able to find an incentive to help lower the costs for 10 years. The team's debt to equity ratio is above one but the team will be using local South Dakota companies for construction to make the project viable. To ensure the power is not expensive, the team spent time on ensuring the price is comparable to other forms of energy by changing the Power Purchase Agreement (PPA) price. The team cannot stop inclement weather, but we can ensure the wind turbines will break (i.ie., rotated to a stalled position) when wind speeds are too high, or hurricanes and tornadoes are present.

All the failures found in ME 486C can be prevented through regular maintenance. Preventative maintenance can detect when a component needs attention. Understanding all the ways a turbine can fail can also help mitigate the risk of a failure. These measures are all important because a failure can cause shutdown that in response reduces the amount of revenue the project can development. The highest risk of failure is the design life of the gearbox. Gearboxes are designed to last 20 years, but most fail in 10 years. This risk needs to be managed through preventative maintenance.

In ME 476C the risks revolved around development, while in ME 486C they were based on post-development risks. Mitigating one risk does not negatively affect the others. This created an ideal situation for creating a safe design. The team does not have to mitigate the post-development risk, as the project goal is to only develop a wind farm, but it was necessary for the team to understand what risks could form. The hardest risks to mitigate were the costs of the project. The team had to find other ways to make the project viable due to the debt to equity ratio being greater than one. In the project simulations, the hardest risk was poor array design. This step took multiple iterations to ensure maximum power output would occur. To mitigate the risks, the team had to problem solve throughout designing the wind farm.

8 ER Proofs

To ensure all parts of the project complete the objectives, all engineering requirements of the final design must be compared to the initial state requirements. The requirements include accessibility, wind production, levelized cost of energy, wind speed, avoiding sensitive areas. Each requirement will be broken down to explain if the requirement was met or not.

8.1 ER Proof #1 – Accessibility

The team was able to prove that this requirement has been satisfied with the design due to the site having access to roads, being near transmission lines, is within a major high wind area, has flat plains, and can be easily accessed by cars. By using Google Earth, the team found a site that fulfilled all of these requirements. This is shown in Figure 5. The black and gray line represent the transmission line through the site and on the map, there are a couple of roads that go throughout the site. By having this site being easily accessible, construction costs will decrease. The accessibility of the site meets the engineering requirement.

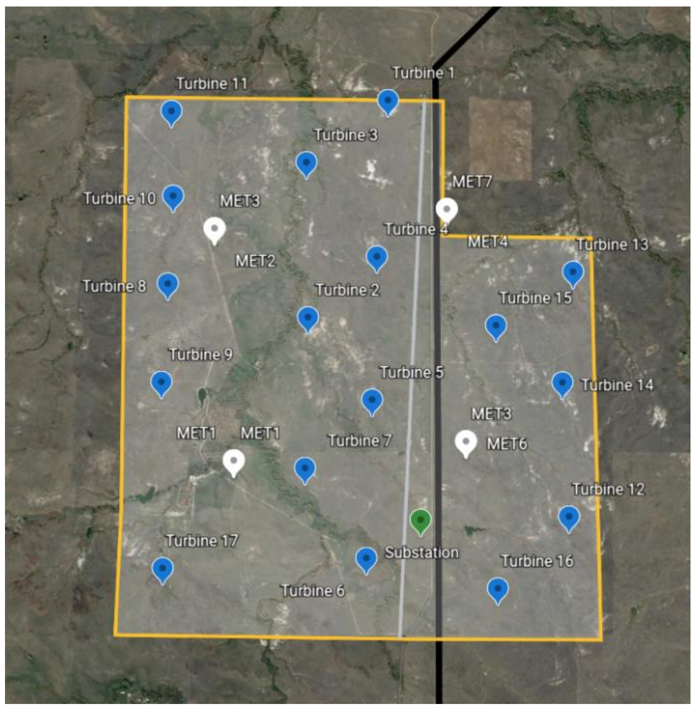

Figure 5: Final Site in Google Earth

8.2 ER Proof #2 – Competitive Wind Production

The team has found that the project is not generating 100MW/year through recent calculations in Continuum. With the current layout that the team has the team is only producing a net 370008.9MWh a year. Displayed in Table 7. Also displayed in this table are the Annual Energy Production a year, AEP, that each turbine produces. With these numbers, the team has determined that the price of this electricity is competitive with solar energy and fuel energy.

Table 7: NET AEP

Site	Net AEP [MWh]
1	23085.5
2	21551.6

3	21007.4
4	21611.4
5	21338.1
6	22246.5
7	21184.3
8	20518.4
9	21807.6
10	20037.9
11	22686.7
12	22518.2
13	22348.2
14	20571.5
15	21163
16	21907.4
17	24425.2

8.3 ER Proof #3 – Levelized Cost of Energy (LCOE)

After performing a cost analysis with the different layouts using SAM, the team found that the PPA price is 7.20 cents/kWh and the LCOE is 5.71 cents/kWh displayed in Table 8. Through this, the team is able to see that the flip year is 18, and although in debt, the team plans to further manipulate these numbers to achieve a lower PPA price. Through the use of this chart, the team can also see how when different numbers change, the PPA price, flip year, and debt may change. The levelized cost of energy is lower than the engineering requirement of 9 cents/kWh including the tolerance. This is beneficial to the team. A lower cost of energy has a higher chance of being profitable.

Table 8: SAM Results Summary

Metric	Value
Annual energy (year 1)	292,183,520 kWh
Capacity factor (year 1)	29.7%
p90 Energy (year 1)	246,985,488.0kWh
PPA price (year 1)	7.20 ¢/kWh
PPA price escalation	1.00 %/year
Levelized PPA price (nominal)	7.42 ¢/kWh
Levelized PPA price (real)	6.07 ¢/kWh
Levelized COE (nominal)	6.98 ¢/kWh
Levelized COE (real)	5.71 ¢/kWh
Investor IRR in flip year	11.26 %
Flip year	18
Investor IRR at end of project	11.38 %
Investor NPV over project life	$6,981,328
Developer IRR at end of project	NaN
Developer NPV over project life	$8,114,202
Net capital cost	$169,736,176
Equity	$71,226,824
Debt	$98,509,360

8.4 ER Proof #4 – Consistent Wind Speed

Although it was predicted that the site would have around 9 m/s winds, from the data that the team currently has, the site has an average of around 8 m/s wind speeds. This wind speed is not the target wind speed (9m/s) for the engineering requirement, but it is within the tolerance (+/- 1m/s). This can be seen in Figure 6. This figure was generated with Wind Prospector data and the use of Continuum. Through these two sources, the average wind speed was found at 100 m.

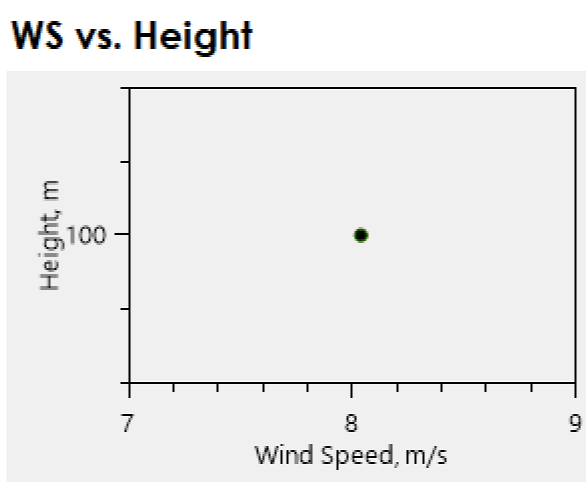

Figure 6: Average Wind Speed vs. Height

8.5 ER Proof #5 – Avoiding Natural and Biological Resources

The main concern that the team avoided was endangered species. Specifically, in Perkins country, the main species that needed to be considered were animal species that the team was already avoiding through the use of Wind Prospector. The specific species that needs to be avoided is the Whooping Crane, Northern Long-eared Bat, and the Swift Fox [17]. All of these species meet the required distance of 50km for the engineering requirement.

9 LOOKING FORWARD

To continue this project, the team recommends continuing simulating in Continuum and SAM to generate different financial analyses along with different power outputs. The team also recommends continuing looking into different permitting and ordinances that would apply to Perkins county. This would secure the procedure going forward along with getting different approvals to construct the site. Through these different steps the project should lead to success.

9.1 Future Testing Procedures

Since this project did not require any kind of CAD model nor physical model, there are no real testing procedures that is needed. The team completed simulations, instead of CAD designs, to design the layout of the power plant.

9.1.1 Testing Procedure 1: Power Output

This section will go into the details about how to simulate a wind farm in Continuum. Through this, wake losses, sound models, ice throw models, shadow flicker models, and AEP can be exported and analyzed.

9.1.1.0 Testing Procedure 1: Objective

To fully setup the map of the site, the land elevation and the land roughness of the site is needed. In order for Continuum to recognize and simulate the site, a 12km radius is needed from the most left, most right, most top, and most bottom MET tower or turbine in the farm. Once the files are ready to be simulated, Continuum will ask for the specific hemisphere and the UTM zone of the site location. This gives Continuum a more accurate way to simulate the real site. When simulated, land roughness, land elevation, total land roughness, and total height displacement can be viewed.

MET tower data can be imported with the use of TAB or CSV files that is generated by Continuum. Once these files are imported, the maps should also import the different turbines and MET tower locations. When MET tower data is imported, analyze the MET towers in Continuum to get the different wind roses and wind directional ratios for the region. Before generating estimates for the turbine, the data for the turbines needs to be inputted. This includes importing the power curve and rated rotational speed is inputted. With the turbine data set, Continuum can now generate turbine estimates of how much energy is produced along with potential losses. Before creating a wake loss map and exporting the data, Continuum needs to first simulate a Monte Carlo analysis and an exceedance model. Once a Monte Carlo value is selected the user then creates an exceedance model.

After these models have been generated, an Eddy Viscosity, Eddy Viscosity Deep Array, and a Jenson model wake loss can be calculated. After selecting a model, a wake map and the AEP and wake losses can be calculated and exported. With the exported data, the needed edits can be easily made.

9.1.1.1 Testing Procedure 1: Resources Required

The needed resources for this program are Wind Prospector, Quantum Geographic Information System (QGIS), United States Geological Survey's, USGS's, National Map Viewer, and Multi-Resolution Land Characteristics (MRLC) viewer. Through the use of Wind Prospector, different wind data sets can be downloaded. With the use of USGS' National Map Viewer and MRLC viewer, land elevation and land roughness data can be downloaded. QGIS is needed to convert the land elevation and land roughness data into TIF files for Continuum to read. The wind data is formatted with the help of Continuum's tool of creating headers. A CSV file is needed to create the turbine layout and power curves for Continuum to read. There is also Continuum tutorials that the developer, Liz Walls, created.

9.1.1.2 Testing Procedure 1: Schedule

The overall time to create a simulation would not only depend on the internet strength on the computer.

Generally, a regular simulation should take around 2 hours at most. The process goes faster once all of the data has been calculated and imported into Continuum.

9.1.2 Testing Procedure 2: Financial Analysis Simulation

This part of the report displays the steps needed to create a financial model for the wind farm.

9.1.2.0 Testing Procedure 2: Objective

To have a full simulation, the team first decided which financial model to follow. With the merchant plant, the developer does not have a buyer to sell the power to the open-market. This option would not be good for the team because the developer would not earn money. The team instead decided to use a Power Purchase Agreement (PPA) Partnership with debt. The power will be sold to the energy company of South Dakota to make the development profitable. The bank will provide loans with this option that the developer will pay back as the project makes money. The team's objective with the financial simulation is to make sure the project is economically viable for the developer and investor.

9.1.2.1 Testing Procedure 2: Resources Required

To make an accurate model in SAM resources are required. The first resource is the wind data in the site location. The team then must put in the turbine characteristics and the turbine array. To lower the debt, incentives were researched and inputted into SAM. Another input was the PPA price. This value changes all the outputs SAM results to.

9.1.2.2 Testing Procedure 2: Schedule

To fully simulate a financial analysis can take around 2-3 hours assuming that all of the needed data has already been researched. The longest part of the simulation is the research. Once the research is complete, the simulation moves very quick. This was essential in making multiple iterations of the finances.

9.2 Future Work

To continue this project, it is recommended that the turbine array be fixed to get the least amount of wake loss possible. South Dakota's policies require further investigation. With the primary values calculated, it is also recommended that another financial model is created to make the flip year lower. By taking these steps, the team expects the final financial analysis to not be in dept and to produce cheap electricity.

10 CONCLUSIONS

In conclusion, the goal of creating a 100MW or less wind farm has nearly been achieved. With a turbine array with a current average of 10% wake loss and a 7.20 cent PPA price, the team achieved the goal of creating a wind farm that has a flip year of 18 years. This current report does not include outside factors including but not limited to construction costs, other incentives that the team can take advantage of, and decommissioning. With the current wind farm, all policies are in place and is prepared to go through the Federal Aviation Administration. The site also avoids endangered species and does not require any type of permits, but the team still plans to donate to local charities and local environmental groups.

10.1 Reflection

Some factors that affected the team includes public health, team safety, and technology. The team did not want to meet in person for safety reasons during the time of COVID-19. With this project being purely research base, the team also found it easier to utilize current technology to meet and discuss the needs for this project. By having the needed programs running, the team was also able to work more efficiently by seeing the different simulations. With the different simulations on hand, the team was also able to determine what should be done in the future. To make sure the power plant is safe, the team is currently creating a risk analysis and is looking into different wind plant insurances. To make sure the design is able to comply with environmental policies, the team plans to hire an inspector for the land to look for potential endangered/protected species.

10.2 Post Mortem Analysis of Capstone

As the team finishes the project, an analysis of the team's work in capstone has been completed. The post mortem analyzes how the team performed. This includes the successes and areas for improvement. The analysis allows the team to reflect on the successes of the project through the positive project performances, tools, methodologies, practices, and technical lessons learned. Even though some aspects were not positive, the team has been able to learn from those mistakes.

10.2.1 Contributors to Project Success

The team's mission was to generate a project development for a wind farm with a preliminary design, financial analysis, risk assessment, and detailed site plan. The team was able to complete each of these things. The wind farm produces less than 100MW a year in the western part of South Dakota. To make the process easier for the team, the team successfully found one landowner that owns more than enough land to create a wind farm on. Through the use of the different tools provided, the team also found that the area has marketable wind speeds. With Continuum simulations, the team is further creating a wind farm that is the most efficient and would not experience high wake losses. Through the use of SAM, the team is also able to gage how much the energy can be sold for and still be profitable for both the locals and the developer. A financial analysis was completed using SAM. Risks of the project were found and learned how to mitigate. The also was able to outline what needs to occur for construction and decommissioning. Throughout the development of the project, the team had positive project performances.

The most positive aspects about this project are that the project only corresponds to one landowner, there are consistent wind speeds on the land, total power generated is less than 100MW a year, close proximity to transmission lines, not interfering with the Whooping Crane migration, and no known interference with tribal lands and other endangered species. Through these aspects, setting up the overall wind farm and getting approved for different permits becomes easier. The team knows that, there are multiple unknowns that would affect the creation of the wind farm in reality but assuming that the process is approved, the team is able to move forward with the creation of the windfarm on the site that the team has decided on. One of the positive aspects regarding the finances of the project is the PPA price and LCOE. The PPA price of 7.20 cents/kWh and LCOE of 5.71 cents/kWh makes the project competitive with other forms of energy. These positives aspects were accomplished through the use of tools, methodologies, and practices.

The tools that contributed most to the project is Continuum, SAM, NREL's wind maps, NREL's endangered species map, NREL's wind tools, QGIS, and JEDI. Through these different resources, the team created a successful wind farm. Continuum was used to understand metrics of the site as well as how much power could be generated. NREL's resources and QGIS were used to find the materials needed for Continuum. Through the use of QGIS, the mapping of the elevation of the land and the land roughness can be further explored without the worry of having to visit the site to gather accurate data. Wind Prospector, NREL tool, provided the average wind speeds, temperature, direction of wind, and altitude for Continuum to use to create the wind roses and to better understand the wind resource on the land provided. SAM was used to perform all the financial models and analyses. These tools allowed the developed information to be accurate, gage energy production, and gage the cost of electricity.

During the project, the team encountered technical hurdles. Some of the technical lessons that were learned throughout this project is how to read wind roses, wake loss maps, utilize QGIS, different mapping tools, and knowing where to research the different aspects of the wind farm. The team also learned that for a project that is similar to the CWC Development Project, it is crucial to start immediately with finding the land with enough wind speeds and to narrow down potential sites and start simulating immediately. Finances were a big part of the project that the team learned throughout the semester. The team learned that projects are cheaper the quicker you start, incentives change yearly, and what selling price energy needs to be set to in order to be profitable. There were lots to learn throughout the semester for this project that spanned from the ordinances needed, species that needs to be avoided, different laws that needed to be researched, incentives that can be easily affect the windfarm, and how the local area and local people can affect the wind farm. The team was able to use their previous knowledge of research in order to be successful. The contributors to project success are understood, so the team can continue being successful in the future.

10.2.2 Opportunities/areas for improvement

During the completion of the project, the team encountered negative aspects that were learned from. The team was able to accomplish the mission, but some areas could be improved on. The team has analyzed which areas could be improved on to enhance the project's performance. To start the analysis, the team first identified which aspects of the project's performance was negative.

The most negative aspects of the project performance are the process of getting approved for permits and the risk management plan. To get different approvals, the team would have to create different layouts and calculate the different outputs with the different configurations that would then have to be evaluated by the Federal Aviation Administration (FAA). The team is currently planning to have 17 turbines and to have two to three extra sites in case the sites do not get approved by the FAA. If the team had more time during the semester, the team would have added in three extra turbine sites to combat this. The team was not able to get too far on the risk analysis and is still looking for different resources to be successful. The team was able to look into different ways to run a wind farm and different ways to insure the wind farm. The team was able to factor in different aspects that would normally be overlooked while creating a wind farm. One of the negative aspects is the debt to equity ratio and flip year. The debt to equity ratio was greater than one, and the flip year is towards the end of the project life at 18 years. These areas would want to be improved on in the future.

The team encountered a multitude of problems including but not limited to software troubles, understanding wake loss models, and understanding where to go for different resources. With these different problems, the team reached out to different people and sites for clarification on the different problems that were encountered. For example, with software issues, the team contacted the developer for guidance on these problems and was then able to create different simulations. To help understand wind roses, the team researched the various sites to understand how to read and fully understand a wind rose. With different wake loss models in circulation, the team has researched the different models that is used for wake losses to understand the wake loss map that is generated in Continuum. To create a windfarm, the team reached out to past winners of the CWC and learned where to go for different resources to create a wind farm along with learning how to weed out the information that is needed for the windfarm. Another problem that the team encountered was having accurate simulations. Continuum predicts the AEP value with the use of data but for the time being, the team only has data from one year. If the team had more time, the team would have formatted the data from as early as 2007 to 2012. With these different data sets, the team has found that a more accurate simulation would have been produced. For financial troubles, the team reached out to industry contacts, to understand incentives that could be utilized for the project. When a problem was encountered, the team used their resources to resolve the problem.

While using the software Continuum, the team experienced multiple difficulties to import data, formatting the different data, and making sure the data was enough for Continuum to use. To overcome this, the team reached out to the developer of Continuum to help resolve some of these issues. The developer helped resolve these issues and even programmed a new version of Continuum to resolve the problems that was being experienced. After resolving the issues, the team created multiple simulations and improved the energy production and minimize wake losses.

Some tools that hindered the performance of the team is the wind turbine's manufactory websites along with difficulty with finding different information for the turbines that was being used. To combat this, the team created power curves for the different turbines that the team decided to use. To find the required information, in regard to permitting for the wind farm, the team investigated Perkins, South Dakota sources along with information from different government department websites.

To improve the performance of the current wind farm, the turbine array can be easily adjusted to get the average wake loss small. The PPA price also would need adjustment so that the team is not in debt and for the flip year of the project to be less than the original 18 years. The team also recommends improving this design by reaching out to turbine manufacturers and explore the different plans that can be offered due to the use of the company's turbines. By doing so, the risk analysis can also be further improved. By utilizing the different insurance plans, the risk analysis would be nearly completed. Analyzing the team's areas for improvements, allows the team to learn how to create a more successful final design. The team will use this information in the analysis to the continue work on the project after the capstone semester. Implementing this analysis into the final design will make the team more competitive during the Collegiate Wind Competition.

Other than technical performance on the siting team, the main issue that was observed was having team members spilt between different groups of the Collegiate Wind Competition. This caused many issues in team dynamics and roles. If any major changes could have occurred, the team would have implemented this change. It is hard for people to work on separate topics, and it was clear to see this during the duration of the project. This piece of information is being passed onto the incoming seniors for the Collegiate Wind Competition 2022.

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12 APPENDICES

12.1 Appendix A: Full First Semester FMEA

Product Name CWC 2021 | Development Team: CWC Turbine | Page No 1 of 1

System Name Siting Team | FMEA Number 1

Subsystem Name Siting Risk Analysis | Date 11/11/2020

Component Name Siting Functions

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
Location	Not in South Dakota	Wrong location	10	Planning error	1	Google Earth	1	10	Revise Google Earth
	Not close to transmission lines	No project potential	9	Planning error	1	Google Earth	1	9	Revise Google Earth
	Energy availability	No energy potential	8	Poor energy modeling	2	Continuum	2	32	Pick new site
	Watershed	Negative environmental impact	5	Lack of research	6	Research	5	150	Reach out to industry professionals
	Transportation of materials	Construction obstruction	5	Lack of outreach	5	Google Earth	3	75	Reach out to industry professionals
	Employee proximity	Construction obstruction	7	Lack of outreach	4	Google Earth	3	84	Revise Google Earth
	City proximity	No location to send energy	7	Poor Google Earth modeling	4	Google Earth	2	56	Revise Google Earth
	Endangered animals	Negative environmental impact	5	Lack of research	3	Research	4	60	Reach out to industry contacts
	Endangered fauna	Negative environmental impact	5	Lack of research	5	Research	4	100	Reach out to industry contacts

	Agricultural production	Negative economy impact	6	Poor Google Earth modeling	6	Research	4	144	Increase research and contact outreach
Energy Generation	Less than 100MW of power	Does not meet requirement	10	Poor modeling	6	Continuum	1	60	Pick new site
	Not enough power for population	Not enough supply	4	Improper planning	6	Continuum	3	72	Population assessment
	Too much power for population	Unused energy	3	Improper planning	4	Continuum	3	36	Population assessment
	Poor turbines	Low energy potential	8	Lack of research	6	Turbine contact	2	96	Reach out to industry contacts
	Poor array	Inefficient energy	6	Inefficient energy design	6	Continuum modeling	4	144	Reach out to faculty advisor
	Land availability	Not enough space required	6	Poor Google Earth modeling	3	Google Earth	2	36	Pick new site
	Land permits	Minimum space allowed	5	Lack of outreach	7	Research	2	70	Reach out to industry contacts
	Poor wind speed	Low energy potential	7	Poor data files	4	Research	2	56	Increase research
	Poor consistency	Not enough energy	6	Poor data files	4	Research	4	96	Increase research
	Inaccurate energy generation	Improper modeling	9	Lack of research and outreach	5	Continuum support	5	225	Reach out to industry contacts
Cost	No government support	Overall increase project costs	5	Lack of research and outreach	6	Research	4	120	Reach out to industry contacts

	No city support	Overall increase project costs	5	Lack of research and outreach	6	Research	4	120	Reach out to industry contacts
	Lack of incentives	No tax breaks	6	Lack of research and outreach	7	SAM	5	210	Reach out to industry contacts
	Low quality	Decrease in life	7	Lack of research on wind farms	4	Research	3	84	Project assessment
	Too expensive for area	Decrease in life	7	Lack of research on SD	3	Research	3	63	SD assessment
	Not viable	Costs > Benefits	10	No finance knowledge	7	Levelized Cost of Energy	4	280	Reach out to business department
	Can not be maintained	Decrease in life	5	No maintenance knowledge	3	Research	3	45	Run JEDI
	High turbine cost	Increase expenses	4	Lack of outreach	4	Turbine contact	2	32	Reach out to industry contacts
	Expensive power	Can't provide power to areas	7	Poor modeling and finance knowledge	5	Continuum	4	140	Run JEDI
	High construction cost	Increase in construction cost	4	No maintenance knowledge	4	SAM	4	64	Run JEDI
Wind	Inconsistent	Energy production	8	Poor wind data	5	Wind data files	3	120	SD assessment
	Available below hub height	Can't obtain energy	7	Poor location	2	Wind data files	2	28	Increase research on SD wind data
	Available above hub height	Can't obtain energy	7	Poor location	2	Wind data files	2	28	Increase research on SD wind data

	Below 6 m/s	Energy production	9	Poor location	1	Wind data files	2	18	Increase research on SD wind data
	Above 22 m/s	Safety hazard	9	Poor location	5	Wind data files	3	135	Increase research on SD wind data
	No energy potential	Incomplete goal of project	10	Not enough wind at location	3	Continuum	2	60	Pick new site
	Hurricanes	Safety hazard	6	Environment	6	Research	4	144	SD assessment
	Tornadoes	Safety hazard	6	Environment	7	Research	4	168	SD assessment
	No wind data	No siting development	10	Lack of research	6	Research	1	60	Reach out to faculty advisor
	Seasonal winds	Seasonal energy production	5	Environment	4	Research	4	80	SD assessment

12.2 Appendix B: Full Second Semester FMEA

Product Name CWC 2021		Development Team: CWC Project Development							
System Name Siting Team									
Subsystem Name Siting Risk Analysis									
Component Name	Siting Functions								
Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
Blade	Wear	Flying Debris	4	Debonding	3	Maintenance	2	24	Preventative Maintenance
	Wear	Flying Debris	4	Joint Failure	3	Maintenance	2	24	Preventative Maintenance
	Wear	Flying Debris	4	Splitting Along Fibers	3	Maintenance	2	24	Preventative Maintenance
	Wear	Flying Debris	4	Gel Coat Cracks	3	Maintenance	3	36	Preventative Maintenance
	Wear	Flying Debris	5	Erosion	3	Maintenance	3	45	Preventative Maintenance
	Inclement Weather	Loss of Function	7	Lighting Strikes	4	Maintenance	1	28	Preventative Maintenance
	Production Failure	Flying Debris and Loss of Function	3	Material or Power Regulator Failure	3	Maintenance	2	18	Preventative Maintenance
	Impact	Flying Debris	5	Damage from Foreign Objects	4	Maintenance	2	40	Preventative Maintenance
	Production Failure	Loss of Function	2	Poor Design	2	Maintenance	4	16	Preventative Maintenance
	Production Failure	Loss of Function	3	Poor Maintenance	4	Maintenance	3	36	Preventative Maintenance
Generator	Inclement Weather	Loss of Function	5	Wind Loading	3	Maintenance	1	15	Maintenance and Repair Program
	Inclement Weather	Loss of Function	4	Weather Extremes	4	Maintenance	3	48	Maintenance and Repair Program
	Wear	Loss of Function	3	Thermal Cycling	4	Maintenance	3	36	Maintenance and Repair Program
	Wear	Loss of Function	3	Mechanical Failure of Bearing	3	Maintenance	2	18	Maintenance and Repair Program
	Design Flaw	Loss of Function	3	Excessive Vibration	2	Maintenance	4	24	Maintenance and Repair Program
	Operation Flaw	Loss of Function	4	Voltage Irregularities	3	Maintenance	2	24	Maintenance and Repair Program

	Design Flaw	Excessive Heat and Fire	5	Cooling System Failure	3	Maintenance	2	30	Maintenance and Repair Program
	Design Flaw	System Breakdown	7	Manufacturing Faults	4	Maintenance	2	56	Maintenance and Repair Program
	Design Flaw	System Breakdown	2	Design Faults	2	Maintenance	4	16	Maintenance and Repair Program
	Assembly Fault	Loss of Function	5	Improper Installation	3	Maintenance	5	75	Maintenance and Repair Program
	Assembly Fault	System Breakdown	4	Lubricant Contamination	2	Maintenance	4	32	Maintenance and Repair Program
	Design Flaw	Loss of Function	5	Inadequate Electrical Insulation	2	Maintenance	4	40	Maintenance and Repair Program
Gearbox	Design Flaw	System Breakdown	6	Design Life	7	Maintenance	5	210	Preventative Maintenance
	Wear	System Breakdown	4	Mechanical Failure of Bearing	4	Maintenance	3	48	Preventative Maintenance
	Wear	System Breakdown	4	Mechanical Failure of Gears	3	Maintenance	3	36	Preventative Maintenance
	Assembly Fault	System Breakdown	3	Dirt Contaminated Lubrication	4	Maintenance	4	48	Preventative Maintenance
	Assembly Fault	System Breakdown	3	Water Contaminated Lubrication	3	Maintenance	3	27	Preventative Maintenance
	Assembly Fault	Loss of Function	4	Improper Bearing Settings	4	Maintenance	2	32	Preventative Maintenance
	Design Flaw	Loss of Function	3	Temperature Fluctuations	5	Maintenance	4	60	Preventative Maintenance
	Poor Maintenance	Loss of Function	4	Improper Maintenance	4	Maintenance	4	64	Preventative Maintenance
	Poor Maintenance	Loss of Function	4	Infrequent Maintenance	5	Maintenance	3	60	Preventative Maintenance
	Wear	Sudden Accelerations and Load-Zone Reversals	5	Transient Loads	2	Maintenance	2	20	Preventative Maintenance
Tower	Assembly Fault	Loss of Function	3	Assembly Errors	2	Maintenance	2	12	Preventative Maintenance
	Poor Maintenance	Loss of Function	3	Improper Maintenance	1	Maintenance	2	6	Preventative Maintenance
	Design Flaw	System Breakdown	5	Poor Tolerancing	5	Maintenance	3	75	Preventative Maintenance
	Design Flaw	System Breakdown	5	Overstressing	3	Maintenance	2	30	Preventative Maintenance

	Inclement Weather	System Breakdown	4	Tornadoes	5	Maintenance	4	80	Preventative Maintenance
	Wear	Loss of Function	4	Erosion	3	Maintenance	4	48	Preventative Maintenance
	Impact	Loss of Function	1	Animal Destruction	2	Maintenance	1	2	Preventative Maintenance
	Impact	Loss of Function	1	Damage from Foreign Objects	2	Maintenance	4	8	Preventative Maintenance